Developing a tyre test machine for AES

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Developing a tyre test machine for AES

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Traineeship report

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Introduction

Nowadays, car-tyres have to meet a number of requirements. The grip of the tyre must be high with acceleration, braking and cornering. Also the rolling resistance must be low. Furthermore the safety and the lifetime of the tyre must be high and the noise-level must be low [1]. All these requirements are more or less the opposite from each other. So a compromise must be made. When the tyre is developed it has to be tested.

There are a lot of ways to test a tyre. Just by driving with a car on the road and inspecting the tyre-behaviour is one way. Another way is building a tyre-tester where a tyre can be pushed against the moving surface of a rotating drum. The surface of the drum can be modeled as a road surface and tests can be performed on it. This has a lot of advantages over testing on road.

In the laboratory of Automotive Engineering Science, the vehicle dynamics group operates with a mechanism on which tyres can be tested. Here, the tyre is pushed against a plank. With this mechanism the tyre is not tested in a way that is similar to how the tyre is used in reality. Therefore another device for testing tyres is desired. In the laboratory of Automotive Engineering Science, a large diameter roller bench is installed. The tyre has to be pushed against this drum. This is done from below the drum. This is done because there is a lot of space below the drums. A mechanism has to be developed to push the tyre against the drum and make the movements that are required.
1. Requirements

There are a lot of requirements the tyre-tester has to satisfy to test the tyres as realistically as possible. Because of the limited amount of time that can be spent on this project, not all requirements are taken into account.

One of the requirements is that the tyre can be pushed against the box with a maximum force of 10 kN. Another very important one is that the tyre must be able to make rotations about his x and z-axis, so rotations $\phi$ and $\theta$. The rotation around the x-axis is called cambering. Figure 1-1 shows what is meant by cambering. The angle that has to be made with cambering is + or - 20°. The rotation around the z-axis is the rotation which has to be made when you are steering the car.

These 2 rotations must be driven by means of a electromotor. The other translations and rotations have to be fixed.

Some other requirements that have to be satisfied are the range of tyres that can be tested with the construction. Here an estimation was made. The size of the rims that are assumed to fit in the construction, run from a diameter of 10 inches to 20 inches. With the height of the tyre this comes to a range of +/- 450 – 710 mm. The tyre is assumed to be 125 - 335 mm width.

Another point is the suspension of the tyre. The tyre is pinned on a cylindrical measurement-hub that can pass on information during the experiment. There are 2 surfaces on this cylindrical measurement-hub which can be used for its suspension.

The midpoint of the tyre in axial direction is at a fixed distance from the middle of the hub.
2. Design considerations

2.1 Place

In the laboratory of the faculty Automotive Engineering Science drive trains 2 drums are located. The space under these drums can be used for the mechanism. This chapter will explain how much room is available for the construction and what the dimensions of the measurement-hub are. As can be seen in figure 2-1 there are 2 walls in between which 2 drums are placed at a distance of 50 mm from each wall. These boxes are placed at a height of 1.85 m and have a radius of 1 m. Between the boxes is a space of 0.9 m. The walls are 1.5 m long and are placed 2.6 m from each other. The walls do not have the same width. Wall 1 is 1120 mm and wall 2 is 450 mm wide.

![Figure 2-1: Overview of the place](image)

2.2 Measurement-hub

The tyre on its rim must be placed on an available measurement-hub. In figure 2-2 the measurement-hub is schematically presented. This hub can measure what is happening to the tyre in 6 degrees of freedom and collects this information and then sends it to a computer. The hub is a cylinder that has a diameter of 250 mm and has a length of 380 mm. At the front of this hub, 2 cylinders, 1 with diameter 170 mm and on top of that 1
with diameter 100 mm with a depth of 10 and 45 mm respectively, are mounted. An adapter can be placed on the front of the hub. This adapter slides over the cylinder with diameter 100 mm. The wheel rim is placed on the adapter. The middle-point of the wheel rim is shifted with respect to the top of the cylinder with diameter 100 mm. This is called the ET-value of the wheel. This value is between -10 and -30 mm. Initially, a constant value of -20 mm is assumed.

Furthermore, the measurement-hub has 2 flat surfaces at the cylindrical wall with which it can be mounted to the fixed world. These surfaces are 90 mm wide and 160 mm in height. To connect this with something there are 4 tapped holes in the surface in which stud-bolts can be mounted.

![Figure 2-2](image.png)

Figure 2-2: Side-view (left), Top-view (middle), Top-view with tyre on the hub (right)

Figure 2-2 illustrates how the tyre is placed on the measurement-hub. Number 1 represents the flat surface on the cylinder with which it can be attached to the fixed world. Number 2 is the tyre which has to be tested. In the right part of figure 2-2 is shown that the middle-point of the tyre is shifted back with respect to the cylinder with number 3. The adapter is placed over this cylinder. In the right part of figure 2-2 the point P is the center of the tyre. This is the point around which the rotations $\phi$ and $\theta$ take place.
3. Construction

In this chapter the construction will be explained in detail. Piece by piece it will be made clear how the construction is built up.

3.1 Suspension-frame

To connect the tyre and the measurement-hub to the fixed world, 2 beams of 200 x 50 x 4 are used. These beams are attached at the 2 walls as can be seen in figure 3-1 and figure 3-2. The beams have a rectangular section which is much higher than width. Because of these dimensions the beams are able to absorb the bending-moment which is created by the force with which the tyre must be pushed against the box.

The beams are attached to both walls. At the place where the beams are attached to the wall grouting is applied and a piece of rubber with a thickness of 1 mm is placed between the wall and the beam. This is done because the concrete of the walls is very rough.

A cylindrical insert prevents compression of the beam by the attachment bolts [2].

Figure 3-1: Top-view with suspension-frame
In figure 3-1 can also be seen how the suspension-frame is attached to the 2 walls.

![Figure 3- 2: Side-view of the suspension-frame](image)

### 3.2 Measurement-hub suspension

As mentioned before the measurement-hub has 2 surfaces by which it can be mounted to the fixed world. The hub has to be able to rotate around his x- and z-axis to get the camber- and steering-movements the tyre has to make. Therefore a mechanism is built that enables these rotations about the given point.

But before that, a sub-frame that can be mounted at the measurement-hub is developed. Because the tyre has to able to rotate around the defined point P (see figure 1-2), the idea was to make this rotation possible with a parallelogram. Figure 3-3 illustrates a parallelogram. The idea behind a parallelogram is that, in this case a triangle, will be copied at another point and that these 2 triangles will be connected to each other by means of 3 parallel struts. When these 2 triangles are connected, they follow each other’s rotation. So when one triangle is rotating around a point, the other triangle follows this rotation, but around another point. A necessary condition for this is that the connection-points are free in rotation. In figure 3-3, Point 1 and point 2 are fixed to the world. They can only rotate. The arrow around point 1 shows the rotation. As a result of this rotation, the same rotation is made around point 2.
This idea will be used to make the steering and cambering movements. But to make this possible, the 3 struts must be attached to the measurement-hub. Also 2 arms that go to the 2 beams that are attached on the walls must be mounted on the measurement-hub.

Further on in this chapter this will be explained in more detail. To explain how this will be mounted at the measurement-hub, figure 3-4 is drawn. Figure 3-4 shows that the construction is symmetric. In the middle the measurement-hub can be seen. At each side of the hub, the flat surface (3) at which the construction can be attached can be seen. In the figure the 3 struts are numbered with a 1. These struts will be pressed between the 2 constructions at the top and at the 2 sides it will be pulled between 2 plates which have a
notch with a radius which has the same dimensions as that of the cylinder. The only difference is that the middle-point of the notch lies outside the profile so the 2 profiles have a space between them so the cylinder will be pulled between them. In figure 3-4 number 4 is a solid plate with that notch which is milled out and which contains the 4 holes, exactly at the same place as at the flat surface (3) on the hub, through which the thread is going. Number 5 is partly solid and partly sectioned. The part that is mounted on the cylinder is solid. The part that is going oblique is a section which is welded on the solid part. At the end of this section a plate (6) is welded which will be used to pull the 2 identical constructions towards each other with a thread (7). The arms (8) that are going to the 2 suspension-beams are also drawn. These arms are a connection of more boxes. This will be explained further on in this chapter. These boxes have the size of the rectangle that is created by the 4 threaded holes in the flat surface on the hub. In the box which is pulled against the hub, the 4 corners are cut out of the box. On these corners, 4 bars are welded and then machined with the middle-point in line with the corner of the rest of the box, see figure 3-5. This is done because the forces go through the plates of the box and they can handle these forces easily. The construction will be bolted together with 4 stud-bolts each side which are in the 4 holes of the flat surface of the hub.

![Figure 3-5: Connection from box to hub](image)

### 3.3 Rotation-mechanism for steering

In paragraph 3.2 the idea of using a parallelogram was introduced, together with the two (identical) triangles. This means that the triangle that created from the suspension-point of the measurement-hub (at both sides of the hub) to the point where the tyre hits the drum has to be copied to some place that is not underneath the drum. This is because, as mentioned in chapter 1, the tyre has to rotate around the middle-point of the tyre by cambering and so the point of driving of this triangle has to be at the same height as the contact-point of tyre and drum as this is only possible between the 2 drums.
There is a space of 900 mm where it can be placed. But before this can be developed there must be an identical triangle which has connection-points that can rotate freely.

As shown in figure 3-6, there are 2 identical triangles (triangle abcd) illustrated. In the left triangle, the original triangle, the point where the tyre and drum 1 touch each other is fixed. The other 3 points (b, c and d) can be chosen freely. The points are chosen so the ball joints are easy to connect to the copied triangle. This explains why the upper ball joint point of the original triangle is placed to the left. When points b and c are chosen above each other, this creates a problem when the ball joint is mounted to the right triangle or a triangle that is not very strong is created.
As explained the ball joints must be connected at 3 points of the triangle that has to be built. In figure 3-7 the copied box is shown with its suspension. In the lower part, the box is drawn. This box has 2 bars ((1) and (6)). These bars are welded to the box. The box is made of 4 plates (5) that are inside the box. These plates make sure the force that is introduced in the box is caught.

Now the ball joints have to be connected to the box. For the lower 2 ball joints, the bar that was mounted to the box (6) is used. At the ends of the bar the ball joints are connected. The other ball joint (4) has another connection to the box. Here a solid block is placed at the kink in the triangle. The ball joint is mounted to the block with a bolt. This block is supported with 2 plates which make sure the block stays in its place. This is important because the forces are going through the bars that connect the 2 triangles.

To make the steering-movement, this box must rotate about the z-axis. Therefore a beam (8) is mounted to the suspension-frame that is attached to the walls. This beam is supported with 2 diagonal beams that make sure the beam for the suspension can not turn over. In the middle of this beam a bar (9) is put through at which a holder for the box can be mounted. This bar is held in place with 2 bearings. The lower bearing makes sure the horizontal translation is fixed and the upper bearing fixes the vertical translation. This is done by putting a cover on the bar. This cover prevents the bar from moving in vertical direction because the bearing is pressed between the bar and the cover and the cover is attached to the suspension beam. At the bottom this bar is connected with the holder for the box. This holder has a U-shape. At both sides of this U a bearing is mounted. This bearing is held in place with the help of a cover. In the U, the bar (1) which is attached to the box can be placed. This bar is placed in bearings to make the cambering-movement possible. This will be explained in paragraph 3.4.

Furthermore, under the suspension-beam is a beam (2) attached to the bar (9) that can rotate. This beam will be driven by an electromotor that is attached to the fixed world. This electromotor drives this beam with a boll screw. This boll screw goes through a nut that is suspended with a cardan from the beam.

### 3.4 Rotation-mechanism for cambering

When the rotation for the steering is developed, only the rotation around the x-axis has to be done. The so called cambering-movement.

This mechanism is integrated in the steering-mechanism because the motor that prescribes the rotation for cambering is then rotating as the tyre is steering. This has the great advantage that the

![Figure 3-8: Motor for cambering](image-url)
The motor can be mounted rigid. The motor drives a boll screw that is put into a nut that is cardanically suspended. Figure 3-8 shows that the motor is mounted to the triangle and that the boll screw goes through the box that is connected to the rotation-mechanism for steering. By rotating the boll screw the box is pulled or pushed away from the cardan suspension with its nut on it. These movements will result in positive or negative camber. No attention is paid to the cardanic suspension. Only some recommendations are made in chapter 4.

3.5 **Slide**

After these mechanisms, a suspension has to be developed. This suspension should not influence the rotations for steering and cambering. This means that this suspension, which consists of 2 arms that are mounted to the measurement-hub, can rotate. These arms are mentioned before in paragraph 3.2. There was explained how these arms are mounted to the measurement-hub.

These arms are built up from boxes (1). These boxes are all made of thin plates. They are welded at each other in a way that the forces are passed on through the boxes and finally end in the suspension-frame (4). The height of the boxes is 160 mm and the depth is 90 mm. These are the same dimensions as the flat surfaces of the measurement-hub. With this height, the rotation of the hub around the y-axis, is assumed to be fixed. More attention on this is spent in the recommendations. When the box, that has the shape of a quarter of a circle, is at the middle-point of the tyre, a bar has to be mounted in the last box. Figure 3-9 illustrates how this was done. The box contains 2 bearings which prevents the bar of translating in
vertical or horizontal direction. On the other side, this bar is mounted to a slide. This slide makes the rotation for the steering possible.
The arms are mounted at the measurement-hub, but because the measurement-hub has not the same height as the slide, the arms must be built upwards as illustrated in figure 3-10.

![Figure 3-10: Arms from hub to slide](image)

The arms with the axis mounted to them must be connected to the slide which is mentioned before. The arms are mounted to a small carriage which can move along a slide. This slide can make an angle of plus or minus 20° with respect to the x-axis. This was also illustrated in figure 3-9.

Figure 3-11 shows in more detail the carriage. The slide will be mounted to the suspension-frame that is mounted to the walls. In the figure this is the right side. At the left side the slide has a triangle-shape. This is done because with this system, the clearance in horizontal as well in vertical direction is pulled out. This is done by preloading the carriage. The figure illustrates that 2 rollers (1) move over the slide. These rollers have a bar with a smaller diameter which is pulled through the rollers. This bar is suspended in 2 bearings, which provide the roller to rotate. These bearings are mounted to a U-shaped holder. This holder is preloaded with a spring. This spring is mounted to the holder of the roller that is pulled to the slide in horizontal direction. This roller is developed in the same way as the earlier mentioned 2 rollers, so with a bar through the roller. The holders of the rollers are mounted together with beams.

This is only 1 part of the carriage. This part is executed twice and they are mounted to each other. In the right part of figure 3-11 this is schematically illustrated.
Figure 3-11: Slide with carriage
4. Recommendations

A mechanical concept has been designed which does not mean that every part is optimized. There are a few things that could be optimized.

The first thing that could be examined is the range of tyres. In this construction not all sizes of tyres can be tested. This is because the middle-point of the tyre is shifting as a result of a change in width of the tyre. This can partly be resolved by putting a cylindrical plate over the adapter so the middle-point can be shifted to its original position. Furthermore, the force that is needed to put the tyre against the box is not mentioned. A possible solution for this is a MacPherson drive. This subject is not dealt with. So in a future project some attention could be given to bringing the force on to the tyre.

In spite of the idea for the cambering-movement, this part could use a more precise idea. The idea for this construction works but there are a lot of other ways to create this movement. Also the fact that a lot of bearings are used, and that the price increases as a result of this, should be a reason to review it. Another reason to review the slide is the fact that dust can easily be departed to the bearings and rolls. This carriage must be made dust-free so the rolls are not damaged.

When the construction is in operation, some problems could occur. One of these problems could be that the measurement-hub is rotating around the y-axis. In the construction this is executed by means of the arm that goes to the slide for the steering-movement. This arm has a height of 160 mm. The assumption that these arms neutralize these rotations was made. In practice this assumption might not be true. A possible solution could be some more blades that obstruct this rotation. These blades could be attached to these arms.

In practice could also appear that the slide for the steering-movement has too much friction so the tests are influenced. This can be solved by another slide system. An extra beam between the slide and the drive of the steering-movement could also solve this.
5. Conclusion

The conclusion of this project is that the construction is able to test tyres. Because of the lack in time it was not possible to make this construction, on a scale, so the idea is based on measurements and calculations. This does not have to be a problem but mostly things that work perfectly in theory do not work or have some restrictions in practice. In the recommendations in the previous chapter some things are mentioned that should be reviewed or has to be developed in future projects. There are the 2 cardanic suspensions and the drive to bring the tyre with a prescribed force to the box. The carriage should be reviewed. This because it must be possible to develop it in a smarter and cheaper way.
Reference


Appendix A: Top-view
Appendix B: Side-view
Appendix C: Front-view